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Effects of soil management in vineyard on soil physical and chemical characteristics

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Abstract. Cover crops in Mediterranean vineyards are scarcely used due to water competition between the cover crop and the grapevine; however, bare soil management through tillage or herbicides tends to have negative effects on the soil over time (organic matter decrease, soil structure and soil fertility degradation, compaction, etc). The objective of this study was to understand how soil management affects soil fertility, compaction and infiltration over time. To this end, two bare soil techniques were compared, tillage (TT) and total herbicide (HT) with two cover crops; annual cereal (CT) and annual grass (AGT), established for 8 years. CT treatment showed the highest organic matter content, having the biggest amount of biomass incorporated into the soil. The annual adventitious vegetation in TT treatment (568 kg dry matter ha-1) that was incorporated into the soil, kept the organic matter content higher than HT levels and close to AGT level, in spite of the greater aboveground annual biomass production of this treatment (3632 kg dry matter ha-1) whereas only its roots were incorporated into the soil. TT presented the highest bulk density under the tractor track lines and a greatest resistance to penetration (at 0.2 m depth). AGT presented bulk density values (upper 0.4 m) lower than TT and penetration resistance in CT lower (at 0.20 m depth) than TT too. The HT decreased water infiltration due to a superficial crust generated for this treatment. These results indicate that the use of annual grass cover can be a good choice of soil management in Mediterranean climate due to soil quality improvement, with low competition and simple management.

1. Introduction

Tillage is the most widely used soil management in the Spanish viticulture as it is a simple technique used to keep under control the water competition that arises with weeds. Nevertheless, tillage accelerates oxidation and eventually the loss of organic matter. When the amount of organic matter in the upper layers decreases, biological activity slows down and the organic matter cycle is weakened [1–5] The use of herbicides decreases the biological activity of soil which consequently decreases organic matter loss due to a lower mineralization, but on the other hand, prevents new biomass incorporation. Therefore, the use of herbicide might keep organic matter content unchanged [6] or might decrease organic matter content between 5.7% and 16% over periods of 5 to 6 years [1,7].

In general, soil management by using grasses or cover crops increases the soil organic matter content, although the extent of this increase depends on the chosen species, cover crop management and environmental conditions [3–9]. Soil management should be employed to mitigate compaction risks and maintain or increase water infiltration rates. Soil compaction is generated by compression processes and its depends on several factors; weight of the machinery, tractor passes, soil water content, texture, mineralogy, soil structure and organic matter content [2,10,11]. These factors cause continuous soil deterioration, decreasing soil porosity, particularly those of larger sizes and increasing resistance to root penetration [2,10,11]. Conventional tillage loosens the surface soil, but can compact the soil below the tillage layer. Nevertheless, no-till soils (herbicides, straw mulch and permanent cover crops) present less compact layers at the same depth [8,12]. Moreover, it is reported that excessive tillage can decrease the organic matter content and the structural stability of the soil [1,2,5,13]. Soils with high organic carbon content (3-4% mass) are less vulnerable to compaction than soils with organic carbon shortage [2,10].

Several authors have observed the beneficial effects that cover crops cause on the physical properties of the soil, preventing structural degradation, erosion, and improving soil trafficability [4,5,13,14].

Compaction improvements in soils managed with cover crops are mainly due to:

a) Reduction in machinery transit, which can be up to 20% [14].
b) Water consumption by cover crops which reduces the water content and limit the compaction effect of machinery transit [1,15]
c) Increase in organic soil matter, which improves aggregate stability, biopore development, total porosity, aeration and infiltration of the soil [1,4,8,13,16].

d) Effect of the cover crop root system that stabilizes aggregates and increases soil resilience, preventing the pressure exerted by machinery to penetrate into deep layers [8, 11, 13, 17, 18].

Despite of these observed compaction improvements, some authors did not find differences in bulk density or penetration resistance between cover crops and tillage in semi-arid vineyard [13, 19], so the soil management effects over the soil compaction depends on the other factors such as soil texture, climatology or cover crops species.

In most soils, water infiltration is influenced by the soil the susceptibility to form a hard pan on soil surface. This depends on physical, chemical and biological characteristics of the soil. Shallow tillage usually increases surface roughness and water infiltration. Nevertheless, tillage decreases soil structural stability and leaves top soil unprotected, and therefore makes it prone to sealing and soil crusting [20]. The observed improvements in infiltration capacity in soils managed with cover crops are due to several reasons. First of all, the biomass generated by the cover crops with its subsequent decomposition improves the soil's characteristics, increases the amount of water that can be infiltrated through the soil profile [1, 4, 21, 22], also protects from crust formation by improving aggregate stability [4, 23], preserving them from the direct impact of rain drops, and finally, increases the number of macropores [23], which increases infiltration rate and reduces water runoff [4, 22]. In general, bare soil gets worse soil characteristics in the long term (decreasing soil organic matter, fertility and infiltration rate, and increasing compaction and erosion). However, the use of cover crops, although improves soil characteristics, increases the competition for water and nutrient immobilization in short term.

There are several studies on the effects of cover crops on soil physical and chemical characteristics, but there are few studies about uses of cover crops in semiarid climates. The objective of this study was to examine the effects of different soil management systems on the physical and chemical characteristics of the soil after eight years in a vineyard under Mediterranean climate conditions.

2. Materials and methods

The trial was carried out in an experimental vineyard located in Madrid (40° 8' North and 3 ° 23' West), at 730 m above sea level, which had been used for cereal production and without vine during at least the previous 15 years. The soil was a calcixerollic Xerochrept type [24] with sandy-clay loam texture, and a pH = 8.5. The climate conditions in that area were continental Mediterranean, with 14 °C annual average temperature, and 450 mm annual rainfall, which 69% was concentrated inside October-April period. The vineyard was planted in 2000 at 2.4 × 1.1 m under drip irrigation. Soil management treatments were set up during the fall of the planting year.

The experimental design consisted of four soil management treatments replicated twice. Each replicate consisted of 120 plants. The experimental single plot size was 237 m^2, with 3 alleys, 4 rows, and 30 plants per row. Soil measurements were taken in the central alleys. All treatments were kept 0.4 m vegetation-free under the vine row by applying an herbicide program. The treatments studied were:

Tillage (TT). This treatment maintained the soil free of vegetation through tillage along the vine growing cycle; it was enough less than four passes from April until November to keep vegetation under control.

Herbicide (HT). This treatment kept a bare soil throughout the year by applying an herbicide. An herbicide application was conducted during the fall with a combination of pre and post-emergence herbicides composed of Glyphosate 36% SL (6 l ha^{-1}), Ixosaben 50% SL (2 l ha^{-1}) and Oryzalin 48% SL (6 l ha^{-1}). In addition a second application of Glyphosate was made during the spring with a dose of 6L · ha^{-1}.

Annual grass (AGT). Soil managed with self-seeding *Bromus hordeaceus* L. cover crop seeded in the fall of 2000 with a seeding rate of 16 kg ha^{-1}. The remaining years, the management of the self-seeding cover crop was limited to mowing and leaving the clippings on the soil surface.

Annual Cereal (CT). Every year a *Secale cereale* L. cover crop was sown during the mid autumn, mowed one month after budburst (around mid May), and leaving the stubble as a mulching during the summer. Sowing took place after preparing the surface around mid-October, when the stubble of the previous year was buried, by means of shallow ploughed (0.1 m depth). Seeding rate was 120 kg ha^{-1}. At tillering moment *Secale cereale* L. 20 units of nitrogen per hectare were applied into the soil.

Date, number of replications and methods used to determine the soil chemical fertility and the other field measures are showed in Table 1.

Vegetation and root dry matter. Aboveground vegetation in the alley (weed and cover crop) was measured using random quadrant. Vegetation was mowed at 0.02 m height. In the same place, root dry matter was obtained with a plant root sampler to a depth of 0.3 m. Each sample was manually washed through a set of 3 graded sieves (2.0, 1.0 and 0.5 mm mesh size). Roots were collected on the sieves. Aboveground vegetation and roots were oven-dried at 65 °C until the constant weight (Table 1). With these data a linear regression was calculated between aboveground vegetation and roots.

Soil bulk density was determined by excavating a trench to a depth of 0.6 m. The sample was obtained using a cylindrical core sampler and it was obtained from cored the sidewall of the trench with the help of a hammer (Table 1).

Penetration resistance measurements were made with a manual penetrometer (Hand penetrometer Eijkelkamp® 06.01) equipped with a manometer with an error of +/−8% for measurements ranging within 200–700 N cm^{-2}. Measurements were reached with a 2 cm^2 cone. Penetration resistance measurements were made under moist soil conditions, so moisture content of the soil was similar in all treatments. Moisture content of the 0.4 m depth soil was about 28% and the differences between treatments were lesser than 2% (data not shown). Penetration resistance and soil bulk density measurements were taken at 0.6 m from line, inside tractor tracks (Table 1). For infiltration measurements two concentric

Table 1. Soil analysis and field measurements methods used in field and laboratory.

Parameters	Method	Date	n
Laboratory analy is[h]			
Organic matter ($g\,kg^{-1}$)	Walkley-black method [31]	April 2008	4[a]
Nitrogen ($g\,kg^{-1}$)	Kjeldahl method [32]	April 2008	4[a]
Extractable phos phorus ($mg\,kg^{-1}$)	Ols en method [33]	April 2008	4[a]
Exchangeable cations ($meq\,100^{-1}$)	Ammonium acetate method [34]	April 2008	4[a]
CEC ($meg\,100g^{-1}$)	Ammonium replacement method [35]	April 2008	4[a]
Field meas urement		March, May, June	
Vegetation and root dry matter TT ($kg\,ha^{-1}$)	Random quadrant and plant root sampler[f]	and October	8[b]
Vegetation and root dry matter HT ($kg\,ha^{-1}$)	Random quadrant and plant root sampler[f]	October and May	8[b]
Vegetation and root dry matter AGT ($kg\,ha^{-1}$)	Random quadrant and plant root sampler[f]	June	8[b]
Vegetation and root dry matter CT ($kg\,ha^{-1}$)	Random quadrant and plant root sampler[f]	May and October	8[b]
Bulk density ($g\,cm^{-3}$)	Cylindrical core sampler[g]	April 2008	4[c]
Penetration res is tance (Mpa)	Manual penetrometer	January 2008	8[d]
Infiltration (S-$mm\,h^{-1/2}$; Ks -$mm\,h^{-1}$ and I-$mm\,h^{-1}$)	Double ring infiltrometer	September 2007 and January 2008	12[e]

[a] Number of replications per depth interval (0-0.1 m, 0.1 m-0.2 m and 0.2 m-0.3 m). 12 samples were analyzed for each treatment.
[b] Number of replications per date. Samples were collected before each tillage (4 times per year)-TT; before each herbicide application (2 times per year)- HT; before mow (1 time per year)- AGT and before mowed and before preparing the soil to sow (2 times per year)- CT. Measures was repeated in 2005, 2006 and 2007. Annual data was calculated to statistical analysis.
[c] Number of replications per depth interval (0-0.1 m, 0.1 m-0.2 m, 0.2 m-0.3 m and 0.3-0.4 m). 16 samples were analyzed for each treatment.
[d] Number of replications per depth interval (0-0.1 m, 0.1 m-0.2 m, 0.2 m-0.3 m and 0.3-0.4 m). 32 samples were analyzed for each treatment.
[e] Number of replications per date (September measurement was made with dry soil and January measurement was made with wet soil) . 24 samples were analyzed for each treatment.
[f] Random quadrat 0.25 m2 and plant root sampler 80 mm diameter, 150 mm high.
[g] Core 50 mm diameter, 51 mm high.
[h] Each sample (above 1 kg) was formed by 6-7 sub-samples of soil, taken on a zig-zag along the alley. Each sub-sample was taken with a cylindrical core sampler (50 mmdiameter × 51 mm high).

cylinders were vertically inserted into the soil down to 0.15 m depth. Water was poured both in the inner cylinder and in the space between both cylinders to make the infiltration readings in the inner ring (Table 1) at 0, 0.04, 0.08, 0.17, 0.25, 0.33, 0.5, 0.75, 1, 1.5 hour (t). The infiltration rate (i_t) for each measurement time was adjusted by a curve according to the Philip's model [25] (1). Sorptivity (S) ($mm\,h^{-1/2}$), hydraulic conductivity (Ks) ($mm\,h^{-1}$) and cumulative infiltration were calculated during the first hour of measurements.

$$i_t = \frac{1}{2} S t^{-\frac{1}{2}} + Ks. \qquad (1)$$

Data were analyzed by ANOVA with the statistical software SPSS v.15.0. Duncan's multiple range tests at 5% significance level were used to compare means among treatments. Simple linear regression was performed with the statistical software SPSS v.15.0.

3. Results

3.1. Chemical characteristics of the soil

Organic matter content was the only soil characteristic that differed between soil management systems at all depths (Table 2). Considering the whole soil profile, CT exhibited the greatest values of organic matter while HT presented the lowest ones. In the top 0.1 m TT and CT had equivalent organic matter content, whereas at deeper soil layers TT and AGT presented intermediate and equal values amongst them (Table 2).

TT had the greatest soil nitrogen content only in the upper 0.1 m of the soil, followed by CT, AGT and finally HT (Table 2). The cation exchange capacity (CEC) presented differences among treatments at the upper and deepest depths, where CT scored the highest CEC (Table 2). Although the remaining parameters did not exhibit differences between treatments at any depth, positive linear relationships were found between the soil organic matter and other soil compounds; total nitrogen ($R^2 = 0.54$), available phosphorus ($R^2 = 0.37$), and exchangeable potassium ($R^2 = 0.59$) and magnesium ($R^2 = 0.86$) (Fig. 1).

3.2. Soil compaction

3.2.1. Bulk density

The bulk density revealed significant differences within the upper 0.40 m among treatments (Table 3). AGT presented lower values than TT which was the treatment that had the greatest bulk density. The values obtained for bulk density are above average for this type of soil [26]. Nevertheless, it should be remembered that the measures shown were made on the tractor track, where compaction is the greatest. Bowen [27] considered that bulk density should be below

Table 2. Soil chemical characteristics at varying depths in the interrow of a vineyard for different soil management treatments after 8 years of trial.

	Soil layer depth 0-0.1 m					Soil layer depth 0-0.2 m					Soil layer depth 0.2-0.3 m				
	HT[a]	TT	AGT	CT	Sig[b]	HT	TT	AGT	CT	Sig	HT	TT	AGT	CT	Sig
MO[d] ($g\,kg^{-1}$)	2.26^{c}	2.98^{a}	2.63^{b}	3.13^{a}	***	1.40^{c}	1.93^{b}	1.91^{b}	2.22^{a}	***	0.97^{c}	1.61^{b}	1.54^{b}	1.98^{a}	***
N($g\,kg^{-1}$)	0.18^{c}	0.23^{a}	0.19^{d}	0.22^{b}	***	0.14	0.15	0.15	0.16	ns	0.13	0.12	0.11	0.13	ns
P($mg\,kg^{-1}$)	22.6	19.5	21.6	15.9	ns	9.03	7.55	6.84	5.61	ns	4.22	2.57	2.97	4.49	ns
K($meq\,100\,g^{-1}$)	0.84	1.07	0.86	0.99	ns	0.56	0.65	0.53	0.60	ns	0.42	0.43	0.39	0.50	ns
M g($meq\,100\,g^{-1}$)	1.56	1.73	1.72	1.74	ns	1.26	1.42	1.30	1.41	ns	1.10	1.28	1.18	1.36	ns
Ca($meq\,100\,g^{-1}$)	16.7	17.3	17.4	14.7	ns	16.7	18.7	17.1	16.0	ns	18.8	18.7	17.9	17.5	ns
Na($meq\,100\,g^{-1}$)	0.16	0.18	0.14	0.14	ns	0.16	0.17	0.07	0.08	ns	0.27	0.17	0.19	0.20	ns
CEC($meq\,100\,g^{-1}$)	19.6^{b}	19.9^{b}	19.2^{b}	21.4^{a}	**	19.6	18.7	19.6	21.3	ns	20.5^{b}	21.0^{b}	20.8^{b}	22.6^{a}	*

[a] Systems of soil management compared: HT = herbicide treatment; TT = tilled treatment; AGT = annual grass treatment; CT = cereal treatment.
[b] Sig = significant probabilities using ANOVA. ns = non significant; * = significant at 0.05 level; ** = significant at 0.01 level; *** = significant at 0.001 level.
[c] Means followed by the same letter do not significantly differ by using Duncan's multiple range test at p = 0.05.
[d] MO = organic matter; N = Kjeldahl nitrogen; P = available phosphorus; K, Mg, Ca, Na = cations exchangeable; CEC = cation exchange capacity.

1.55 $g\,cm^{-3}$, so that root development would not be limited in soils of clay-loam texture; Although our soil is a sandy-clay loam, the critical bulk density should be slightly above this benchmark. AGT showed values close to this threshold and therefore, the remaining treatments will have a severe limitation to root development due to their soil compaction.

3.2.2. Penetration resistance

Differences among treatments were evident within the upper 0.2 m of soil (Table 4) which is the management altered soil layer either through mechanical work, or by seeding the cover crop, or eliminating vegetation by herbicides. At levels deeper than 0.2 m, soil kept its original structure and revealed no differences between soil managements. TT had the lowest penetration resistance values in the 0.1 m of top soil. At 0.2 m depth, TT revealed the highest values due to its hard pan developed by tillage practice while CT did the lowest values. At this depth, AGT and the HT had the same behavior and no statistic differences were found compared to the rest of the treatments. Root penetration limit tended to be between 2 and 2.5 MPa [28,29]. This limit was reached by HT and TT at 0.2 m depth while AGT and CT reached it at 0.30 m depth; Therefore, CT and AGT treatments could have had a more intense root development in the shallower layers under the tractor truck than TT and HT. No statistical differences were found neither at 0.3 nor 0.4 m depth (Table 4).

3.3. Infiltration

The high correlation coefficients between mean measured values and the Philip's model indicated that the model fitted well to the field measurements (Table 5).

Sorptivity did not show statistical differences between treatments. Both hydraulic conductivity and infiltration accumulated along the first hour of readings showed statistical differences among treatments. Hydraulic conductivity (Ks) in HT was the lowest while no differences were found among the other treatments. Infiltration accumulated was maximum in CT and minimum in HT, while TT and AGT presented intermediate values without statistical differences compared to the rest of the treatments (Table 5).

4. Discussion

4.1. Chemical characteristics of the soil

Variations in soil organic matter content depend on the equilibrium between the amount of organic matter provided and its mineralization rate. In this study, organic matter contribution was the highest in CT and the lowest in HT. On the other hand, biomass management generated by each treatment also had effects over the soil organic matter content. Likewise, by incorporating the biomass generated for adventitious plants in the TT scenario, the soil organic matter is preserved at similar level to AGT treatment. The aerial biomass generated by AGT was six times greater than that generated by TT (Table 6). However, since this treatment did not involve tillage, mainly the underground part of the cover crop (approximately 25% of the aerial part) was truly incorporated into the soil (Fig. 2) while in TT all the biomass generated by the adventitious plants was incorporated into the soil. This way, the real amount of biomass incorporated into the soil was very similar in both treatments.

Although no statistical differences were found in soil nutrient content among treatments, an adequate cover crop management might increase nutrient content over time (Fig. 1). The significant relationships between organic matter content the rest of nutrients (nitrogen, phosphorus, potassium and magnesium) in the soil indicate the dependence of soil fertility on organic matter content. The study of these relationships by single treatment showed that the herbicide had different behavior compared to other treatments (except in the relationship between organic matter and exchangeable magnesium). Likewise, these differences could be due to slope changes (Kjeldahl nitrogen and exchangeable potassium with organic matter) or intercept changes (available phosphorus

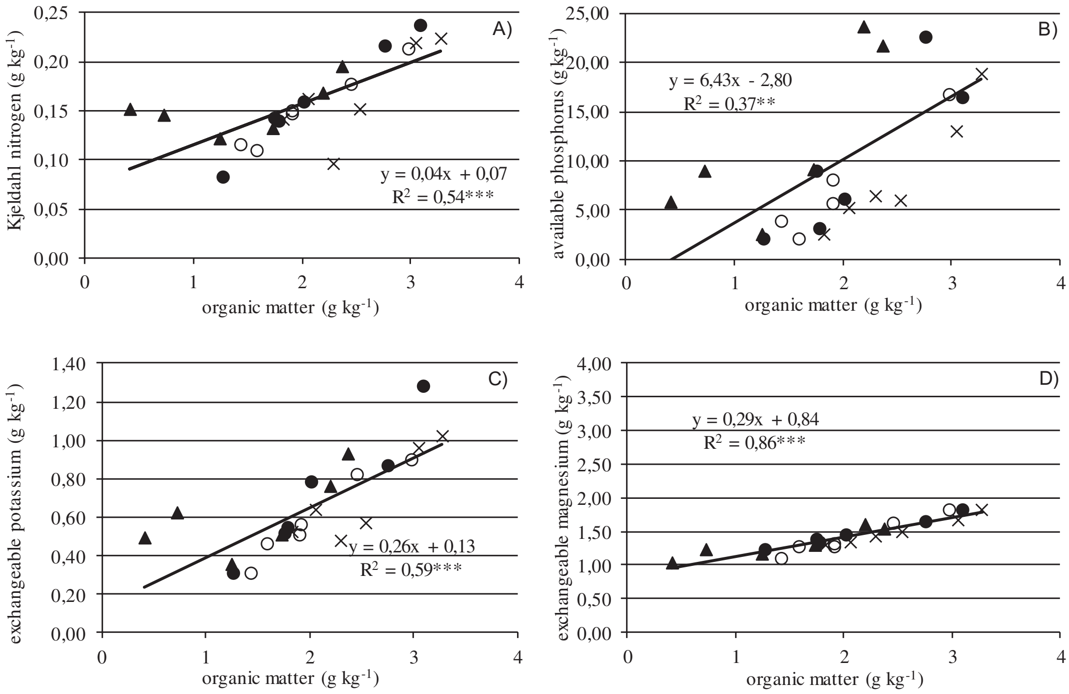

Figure 1. Relationship between organic matter and Kjeldahl nitrogen (A),available phosphorus (B), exchangeable potassium (C), and exchangeable magnesium (D) of soil measured at 0-30 cm depths in the interrow. ▲ herbicide treatment; • tilled treatment; ○ annual grass treatment; x cereal treatment. ns = non significant; * = significant at 0.05 level; ** = significant at 0.01 level; *** = significant at 0.001 level.

Table 3. Soil bulk density under the wheel track in a vineyard with different soil management treatments after8 years of trial.

	Soil layer depth 0-0.4 m				Factor Sig[b]		
	HT[a]	TT	AGT	CT	Management	Depth	Management x Depth
Bulk density (gcm^{-3})	1,75 ab[c]	1,86[a]	1,60[b]	1,74[ab]	*	**	ns

[a] Systems of soil management compared: HT = herbicide treatment; TT = tilled treatment; AGT = anual grass treatment; CT = cereal treatment.
[b] Sig = significant probabilities using ANOVA. ns = non significant; * = significant at 0.05 level; ** = significant at 0.01 level; *** = significant at 0.001 level.
[c] Means followed by the same letter do not significantly differ by using Duncan's multiple range test at p = 0.05.

with organic matter). In addition, the HT correlation coefficient was always lower compared to the other treatments.

In fact, in the first 0.1 m statistical differences were observed in nitrogen content, with the greatest organic matter content presenting the highest total nitrogen values (Table 2). Thus an annual cover crop would be the most recommended soil management strategy to increase soil fertility. The higher soil organic matter content the higher soil fertility (i.e. CEC).

4.2. Soil compaction

4.2.1. Bulk density

Several authors have shown how machinery and/or tillage can increase bulk density in the soil, generating compaction problems at greater soil depths [2,10,11,30]. The low bulk density observed in the AGT was due to three main causes:

a) Reduced machinery traffic; since tillage, seeding and herbicide practices were not necessary. Machinery circulation in AGT was decreased by 25% as compared to TT and CT, and by 14% compared to the HT.
b) The protecting effect of the cover crop's root system throughout the whole year; efficiently prevented compaction in deeper layers [11].
c) The increase in total porosity and soil aeration due to root activity [1,6,15] and aggregate stability due to the organic matter supplied by roots [3,13,18].

CT and HT presented intermediate bulk density values, though statistically equal to the rest of the treatments. In the HT scenario, reduction in soil organic matter made this treatment more susceptible to compaction; however, the decreased in machinery traffic resulted in a similar bulk density as compared to the other treatments. On the other hand, in CT scenario, the protecting effect of the root system and the increase in the soil organic matter content

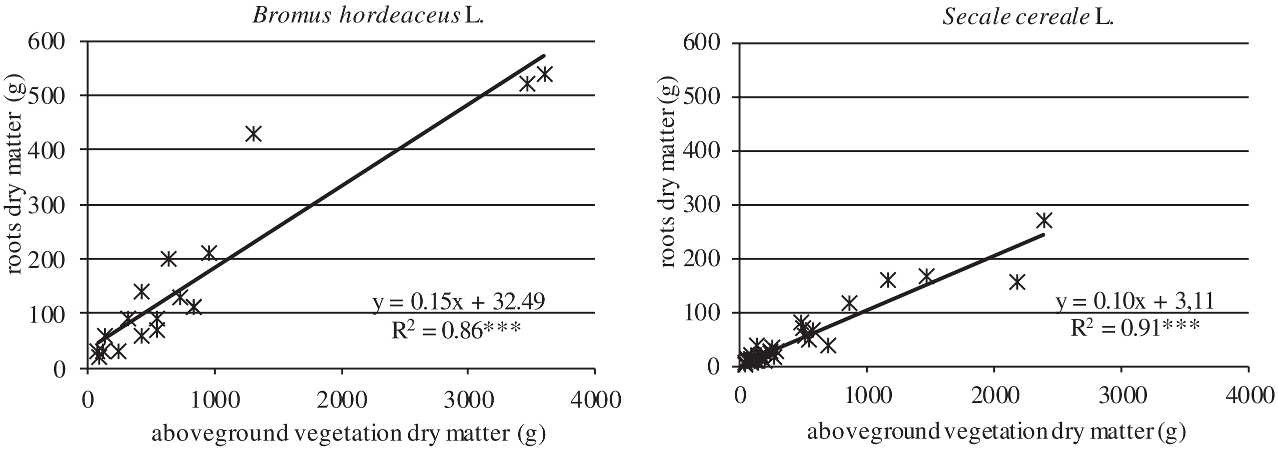

Figure 2. Relationship between Bromus hordeaceus L. (annual grass) and Secale cerale L.(cereal) aboveground vegetation and roots dry matter. $***$ = significant at 0.001 level.

Table 4. Penetration resistance (MPa) at varying depths in wheel tracks of a vineyard for different soil management treatments after 8 years of trial.

	Soil Management				Factor Sig[b]		
Soil layer depth	HT[a]	TT	AGT	CT	Management	Depth	Management x Depth
0-0.1 m	1.62[ac]	1.06[b]	1.43[a]	1.51[a]	***	-	-
0.1-0.2 m	2.67[ab]	3.27[a]	1.99[ab]	1.59[b]	*	-	-
0.2-0.3 m	3.33	2.96	3.31	3.61	ns	-	-
0.3-0.4 m	3.89	3.95	4.36	4.44	ns	-	-
Total	2,88	2,81	2,77	2,79	ns	**	**

[a] Systems of soil management compared: HT = herbicide treatment; TT = tilled treatment; AGT = annual grass treatment; CT = cereal treatment.
[b] Sig = significant probabilities using ANOVA. ns = non significant; * = significant at 0.05 level; ** = significant at 0.01 level; *** = significant at 0.001 level.
[c] Means followed by the same letter do not significantly differ by using Duncan's multiple range test at p = 0.05.

prevented a higher soil compaction, despite the traffic and the heavy tillage carried out in this treatment (Table 2).

4.2.2. *Penetration resistance*

Tillage radically decreased penetration resistance in the upper 0.1 m of soil (Table 4); however, the mechanical pruning of vineyard roots in this superficial layer prevented to vine roots from making the most of these improvements. This pattern drastically changed from 0.1 to 0.2 m depth. In this layer, tillage presented the highest penetration resistance as compared with the CT (Table 4). Machinery traffic and the increased number of tillage passes developed a hard plow layer at this depth. It appears that CT had a certain protective effect against soil compaction at that depth. This effect could be attributed to the increase in soil resilience caused by cereal rooting [11] although it could also have affected by the increase in organic matter content, the stability of structure or biopore development after cereal root turnover [1,4,5,13,16]. A similar trend was observed in AGT, although differences were not significant due to its smaller root development. The low compaction with CT as compared to the TT is of great importance in woody crops where the effects accumulate year after year.

Although the penetrometer is frequently used to estimating the pressure that roots are developing to penetrate through soil, this measurement has its own limitations since penetration resistance varies due to internal resistance exerted by the roots of the cover crops, although this increase in resistance values are not associated with an increase of the difficulty in grapevine roots development [10]. Therefore, despite not finding statistical differences between the herbicide and the cover crop treatments, it might be possible that vine roots do not need to exert as much force in soils managed with cover crops as in those managed with herbicides.

4.3. Infiltration

Herbicide applications in sandy-clay loam soils created a strong superficial crust which decreased both accumulated infiltration and hydraulic conductivity. Through tillage and cover crops, soil hydraulic conductivity improved due to an increase in large pore percentage at the surface (Table 5). This increase in the pore average size is achieved by crumbling the superficial crust by tillage or by improving the soil structure and increasing the number of biopores that the use of cover crops causes [23]. Hydraulic conductivity improvements have enabled soil management with cereal to double the volume of infiltrated water during the first hour of measurement as compared to soil managed with herbicide. This increase in infiltration rate associated with cover crop management has been reported

Table 5. Infiltration in the interrow of a vineyard for different soil management treatments after 8 years of trial. Infiltration data averaged with dry and wet soil.

	Soil management				Factor sig[b]		
	HT[a]	TT	AGT	CT	Management	Date	Management x Date
$S^d (mm\,h^{-1/2})$	7.76	7.17	8.13	10.73	ns	ns	ns
$Ks\,(mm\,h^{-1})$	0.68^{bc}	6.29^{a}	5.25^{a}	6.40^{a}	*	**	ns
$I\,(mm\,h^{-1})$	10.38^{b}	12.79^{ab}	17.56^{ab}	24.56^{a}	*	**	ns
R^2	0.971	0.963	0.983	0.994	-	-	-

[a] Systems of soil management compared: HT = herbicide treatment; TT = tilled treatment; AGT = annual grass treatment; CT = cereal treatment.
[b] Sig = significant probabilities using ANOVA. ns = non significant; * = significant at 0.05 level; ** = significant at 0.01 level; *** = significant at 0.001 level.
[c] Means followed by the same letter do not significantly differ by using Duncan's multiple range test at p = 0.05.
[d] S = sorptivity; Ks = hydraulic conductivity ; I = total infiltration; R^2 = determination coefficient obtained with linear regression between Philip infiltration model and means experimental data.

Table 6. Annual mean (2005–2007) aboveground vegetation dry matter in the four soil management treatments studied.

	Soil management				Factor sig[b]		
	HT[a]	TT	AGT	CT	Management	Date	Management x Date
Dry matter $(kg\,ha^{-1})$	3^{dc}	568^{c}	3632^{b}	8824^{a}	***	**	ns

[a] Systems of soil management compared: HT = herbicide treatment; TT = tilled treatment; AGT = annual grass treatment; CT = cereal treatment.
[b] Sig = significant probabilities using ANOVA. ns=non significant; * = significant at 0.05 level; ** = significant at 0.01 level; *** = significant at 0.001 level.
[c] Means followed by the same letter do not significantly differ by using Duncan's multiple range test at p = 0.05.

in other trials [4,21]. The intense infiltration measured in CT was due to the fact that this treatment combines the improvements made by the tillage in preparing the soil bed for seeding and the cover crops during the winter. Even the mulch was useful to decrease runoff and accumulate rainfall in areas of heavy rains at the end of the summer. By choosing the appropriate cover crop that will dry out at the end of rainfall period in spring could obtain key improvements on water availability during berry maturation.

5. Conclusion

Soil management modified the soil physical and chemical characteristics after 8 years of trial. Soil organic matter content was the main factor affected by soil management which depended on actual amount of biomass incorporated into the soil and not of total amount produced by the cover crop. Although the rest of chemical parameters did not show differences among treatments, relationship between organic matter and other parameters show the beneficial effects of the cover crops.

Bulk density and penetration resistance decreased by the use of cover crops.

Soil managed with herbicides in sandy-clay loam soil generated a superficial crust that limited the infiltration severely. The superficial crust could be broken by tillage; however, this technique generated other problems such as compaction. These results indicate that the use of cover crops in a Mediterranean environment can improve soil structure and increase soil porosity, enhance infiltration rate and reduce soil compaction and superficial crusting. Cereal Cover crop (CT) should be recommended for low fertility soils due to its capacity to improve soil fertility through biomass incorporated into the soil whereas a self-seeded cover crop, such as *Bromus hordeaceus* L. should be used when limited water competition and simple management is desired.

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